Assimilation of Long-Range Lightning Data over the Pacific

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LONG-TERM GOALS

A Pacific Lightning Detection Network (PacNet) has been constructed with support from ONR and NASA. PacNet currently consists of four hybrid receivers, two sited in Hawaii, one in the Marshall Islands, and one in the Aleutian Islands (Fig. 1). Together the PacNet sensors continuously monitor sferics over the central Pacific Ocean and adjacent land areas. The long term goals of this and a follow-on project are to expand PacNet to cover the western Pacific Ocean with 8 additional sensors to be installed in 2008. In addition the project aims to support operational utilization of the data stream at NRL for (i) nowcasting convective activity, (ii) convective rainfall analyses over the Pacific, and (iii) to improve marine prediction of cyclogenesis and squall-line motion through sferics data assimilation in COAMPS and NOGAPS. Technology transfer to NRL will be accomplished in close collaboration with NRL scientists, with data processing and analysis support from Vaisala and NASA scientists.

OBJECTIVES

The scientific and technical objectives of the Pacnet project are to collect long-range lightning data over the central and north Pacific Ocean, refine the relationship between lightning and rainfall rates and work toward implementation of operational assimilation of lightning derived products into COAMPS and NOGAPS.

APPROACH

Diabatic heating sources, especially latent heat release in deep convective clouds play an important role in storm development and dynamics. Lack of observations over the Pacific Ocean can lead to inadequate initialization of the numerical models and large errors in storm central pressure and rainfall forecasts. Specifying diabatic heating sources in the early hours of the forecast can improve the model's performance. Data from Pacific Lightning Detection Network (PacNet) are used to identify the areas and intensities of convective activity and latent heat release in storms over the Pacific Ocean.

Our hypothesis is that in cases of cyclogenesis in marine air masses, including subtropical cyclogenesis, the relationship between rainfall and lightning rates will be relatively robust because the aerosol and cloud microphysical environment is more uniform. Results of our comparison of the lightning rate measured by PacNet and convective rainfall obtained from Aqua's and TRMM's microwave sensors for a variety of storm systems over the central north Pacific indicate that the ratio

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14. ABSTRACT
A Pacific Lightning Detection Network (PacNet) has been constructed with support from ONR and NASA. PacNet currently consists of four hybrid receivers, two sited in Hawaii, one in the Marshall Islands, and one in the Aleutian Islands (Fig. 1). Together the PacNet sensors continuously monitor sferics over the central Pacific Ocean and adjacent land areas. The long term goals of this and a follow-on project are to expand PacNet to cover the western Pacific Ocean with 8 additional sensors to be installed in 2008. In addition the project aims to support operational utilization of the data stream at NRL for (i) nowcasting convective activity, (ii) convective rainfall analyses over the Pacific, and (iii) to improve marine prediction of cyclogenesis and squall-line motion through sferics data assimilation in COAMPS and NOGAPS. Technology transfer to NRL will be accomplished in close collaboration with NRL scientists, with data processing and analysis support from Vaisala and NASA scientists.

15. SUBJECT TERMS

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of lightning to rainfall rate shows a relatively stable relationship over the Pacific Ocean. This suggests that lightning data over the Pacific can be assimilated into numerical models as a proxy for latent heat release in deep convective clouds.

Personnel and their tasks for the Project

At UH, Professor Steven Businger, the PI, is working with Antti Pessi, PhD. student, on the data assimilation. Kirt Squires, MS student is working on lightning in tropical cyclones. Duilia Mora, undergraduate student, is looking at climatology and distribution issues as a senior thesis topic.

Ken Cummins at the University of Arizona and Nicholas W. S. Demetriades at Vaisala are collaborating with UH in using NLDN and PacNet data to calibrate the network. Ken is also working with Antti Pessi to develop a detection efficiency model for PacNet.

At the Naval Research Lab in Monterey, Dr. Allen Zhao will collaborate with Antti Pessi on data assimilation studies. Dr. Joe Turk will investigate nowcasting applications of the lightning data stream over the Pacific.

WORK COMPLETED

Previously lightning data from PacNet were assimilated into MM5 by two methods. The first method capitalizes on a lightning-rainfall-moisture profile relationship. The method involves a Four-Dimensional Data Assimilation (FDDA) of lightning data into MM5. The model predicted vertical moisture profiles are nudged towards moisture values inferred from lightning data.

The second method capitalizes on the relationship of lightning rate and latent heating profiles. This method involves modifying the Kain-Fritch convective parameterization scheme in the MM5 code, and a lightning data input file is constructed. The method scales the model's vertical latent heating profiles at each gridpoint and model level, depending on the ratio between model predicted rainfall and rainfall derived from the lightning data. Scaling is done only if the observed rainrate, derived from lightning, is greater than model predicted rainrate. As reported in our previous annual reports, both methods significantly improved the location and strength of the storms studied (Pessi et al. 2005). It was found that the latent-heating method has distinct advantages for operational implementation. In particular, construction of the moisture profiles requires prior knowledge of the temperature, whereas latent heating scaling technique is independent of environmental temperature, making this approach more robust.

Work completed since the last annual report

Significant advances have been made on several fronts during the past year.

i) Refinement of the location accuracy and detection efficiency of PacNet has continued and an improved DE model was implemented at UH (e.g., Fig. 2)(Pessi et al. 2008). This is an important research agenda because it facilitates the use of the PacNet data in quantitative applications such as numerical weather prediction (NWP). Currently, data from the NLDN over the mainland US and local lightning data from Puerto Rico are being analyzed to further refine both the LA and DE models used for long-range lightning estimates. Given that long-range sensors measure primarily cloud-to-ground strokes, this latter approach does not suffer from the ambiguity that the choice of the ratio of cloud-to-cloud to ground strokes introduces when using the TRMM LIS data for calibration. Results from this new effort are expected within the month.

ii) The log-linear relationship between lightning rates and rainfall rates (Fig. 3) has been further refined, using additional TRMM and PacNet data (Pessi and Businger 2008).

iii) The sensitivity of the model results to changes in the DE model has been investigated (Fig. 4). In the sensitivity study the estimated lightning rates were increased and decreased by 50% to see the impact on simulated cyclogenesis.

iv) Dynamic analysis of model output for the case of a strong eastern Pacific midlatitude cyclone has undertaken to provide insight into the mechanism by which thunderstorms along a cold front cause deepening of the storm central pressure (Fig. 5).

RESULTS

The results from the refined DE model have been used to produce a strategy for expansion of PacNet to cover the western Pacific Ocean (Figs. 1 and 2). Installation of eight sensors is planned for 2008, resulting in greatly expanded coverage. The expansion of PacNet will be supported under a follow-on award to the current one.

The results of the refinement of the log-linear relationship between lightning rates and rainfall rates was implemented in a study of the sensitivity of a modeled storm's intensity to changes in the DE. The results show that the modeled storm's central pressure is not overly sensitive to the value of the DE used in the assimilation of lightning data. Although the run with 150% increase in lightning rate resulted in more rapid deepening of the storm, the central pressure attained was only one mb lower than that using the default DE.

Analysis of the dynamics of simulated rapid cyclogenesis in a storm off the US West Coast shows that lightning and latent heating increased the temperature gradient across- and winds along the cold-front and this enhanced the low-level advection of high theta-e air over the storm center and thus dropping the surface pressure hydrostatically (Fig. 5). Evolution of this important dynamical process in the model was illustrated in Pessi and Businger (2007).

In the paper by Squires and Businger (2008), which is now in press, the eyewalls of hurricanes Rita and Katrina are shown to have extraordinary lightning flash densities when compared to historical storms (Fig. 6). Both storms' eyewalls contained their greatest hourly flash density during a period of rapid intensification (Fig. 7). LLDN detected lightning strikes in hurricanes Rita and Katrina were closely collocated with areas of intense convection, as determined by aircraft radar reflectivity and TRMM precipitable-ice product data (Figs. 8 and 9). Maxima in eyewall flash density were collocated with maxima in flight-level reflectivity (e.g., Figs. 8 and 10). Therefore, by using the lightning data as a proxy for convective intensity, it may be possible to continuously monitor the convective evolution within hurricane eyewalls through close examination of the evolution of the LLRD lightning data.

IMPACT/APPLICATIONS

Long-range lightning data can be used to aid the real time examination of active convective areas within the eyewall of TCs. As a result of the masking effects of high cloud blow-off, it is often difficult to track the motion of individual convective areas within the eyewall region. Using continuous lightning data overlaid onto these infrared satellite images would allow for much better tracking of any area of active eyewall convection, which is producing cloud to ground lightning. For a convective system to produce the flash rates that were recorded in both Rita and Katrina, a modest amount of CAPE within the eyewall environment is necessary. The eyewall lightning within these two storms was also maintained for many consecutive hours, sometimes for more than a day. Therefore, the results of this limited study suggest that for some extended periods of time, appreciable values of CAPE are present within the eyewall of some mature hurricanes. The better understanding of the structure and evolution of the eyewall convection while the TC is still over the open ocean, could lead to more accurate intensity forecasts.

An effort has been made during the past year in quantifying the detection efficiency of PacNet, an important step toward operational application of the lightning data stream. With the planned expansion of PacNet to the western Pacific Ocean, and continued calibration of PacNet, the quality and coverage of the data stream will continue to improve in support of our primary goal. The primary goal of the project is to assimilate the lightning data employing COAMPS and 3-D variational data assimilation. Sensitivity tests of the latent heating method of data assimilation to variations in DE conducted at UH are very promising. The success of the latent heating method holds promise for application in a variety of settings, including tropical cyclones.

RELATED PROJECTS

NASA MSFC, in collaboration with Vaisala Thunderstorm Unit and UH, has contributed to the calibration of PacNet, using LIS on TRMM.

European VLF-Detector Network: The European Community has been actively developing a VLF lightning detection network in Europe. Contact has been made with one of the principals (Chris Kidd at the U of Birmingham, C.Kidd@bham.ac.uk) in that effort to facilitate synergy and scientific exchange.

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Pessi, A. T., and S. Businger, K. L. Cummins, N. W. S. Demetriades, 2008: A long-range lightning detection network for the Pacific: construction, performance, and applications of the data stream. *J. Atmos. and Ocean. Tech*., in review.

Pessi, A. T., and S. Businger, 2008: Relationships between lightning rate, rainfall rate, and hydrometeor profiles over the North Pacific Ocean. *J. Appl. Meteor.*, in review.

Squires, K. and S. Businger, 2008: The Morphology of Eyewall Lightning Outbreaks in Two Category Five Hurricanes. Mon. Wea. Rev., in press.

PUBLICATIONS

Pessi, A. T., and S. Businger, K. L. Cummins, N. W. S. Demetriades, 2008: A long-range lightning detection network for the Pacific: construction, performance, and applications of the data stream. J. Atmos. and Ocean. Tech., in review.

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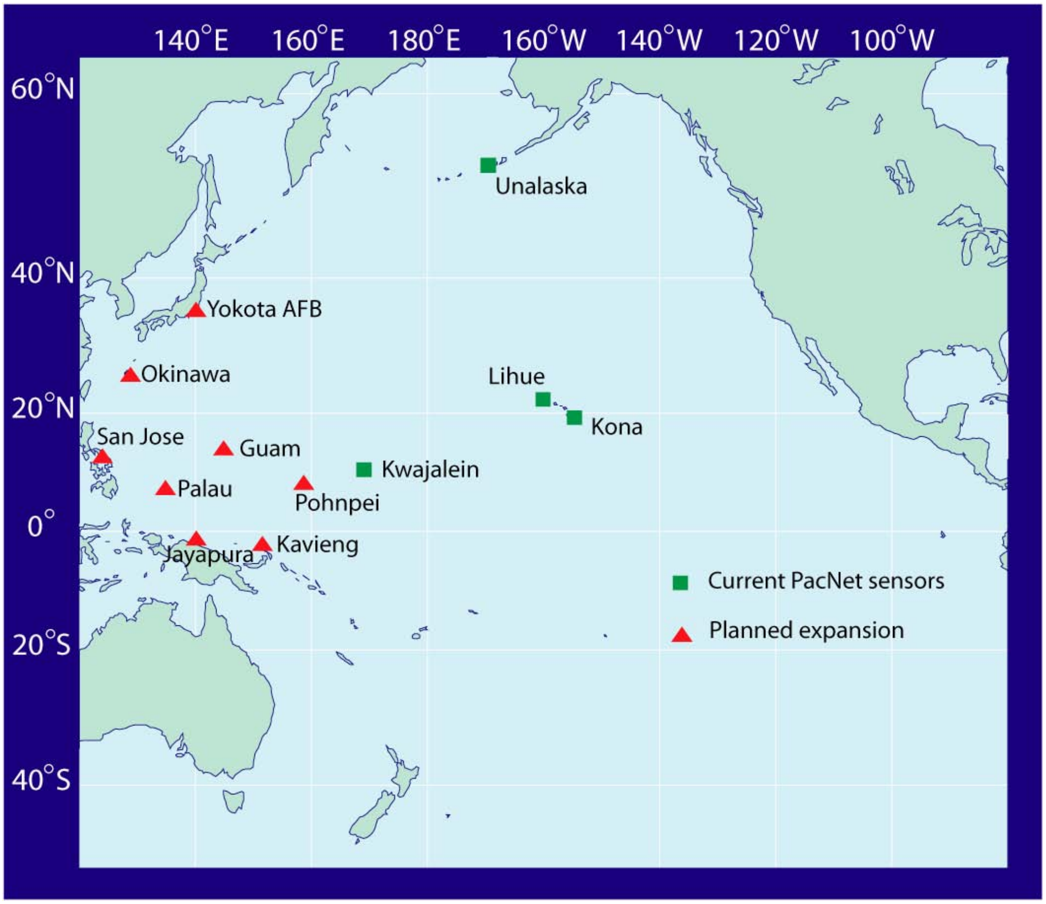

Fig. 1 PacNet's current lightning detector sites (green) and planned future sites (red). Data from detectors located in Japan and along the west coast of the U.S. are used in the processing stream received at the Vaisala Thunderstorm Unit to complement the PacNet data.

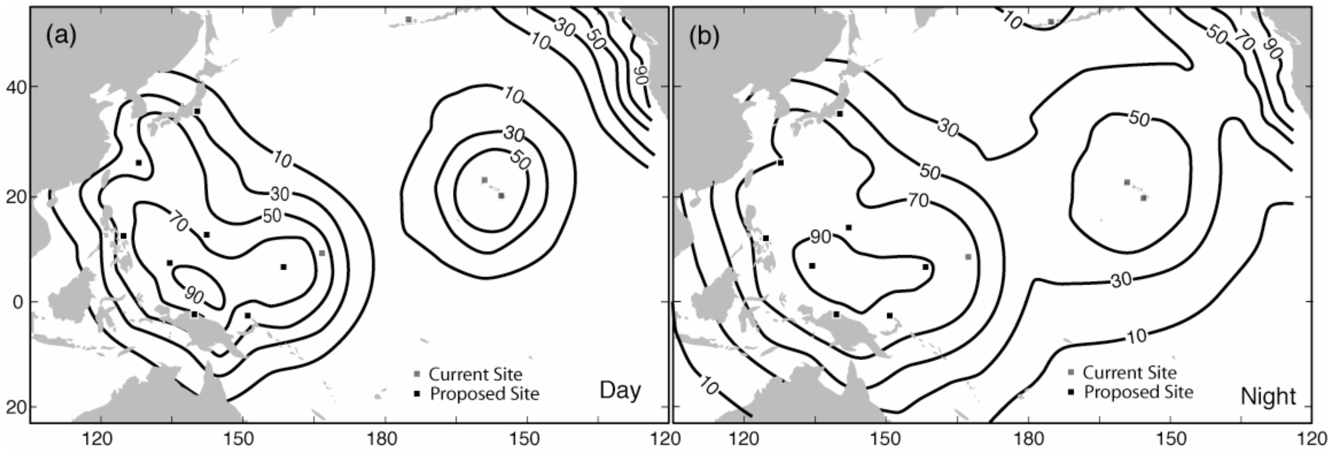

Fig. 2 Modeled detection efficiency (%) over the north Pacific Ocean (a) during the day and (b) at night. Modeled DE does not consider the contribution from Asian sensors, which will improve the coverage, particularly to the west of Japan.

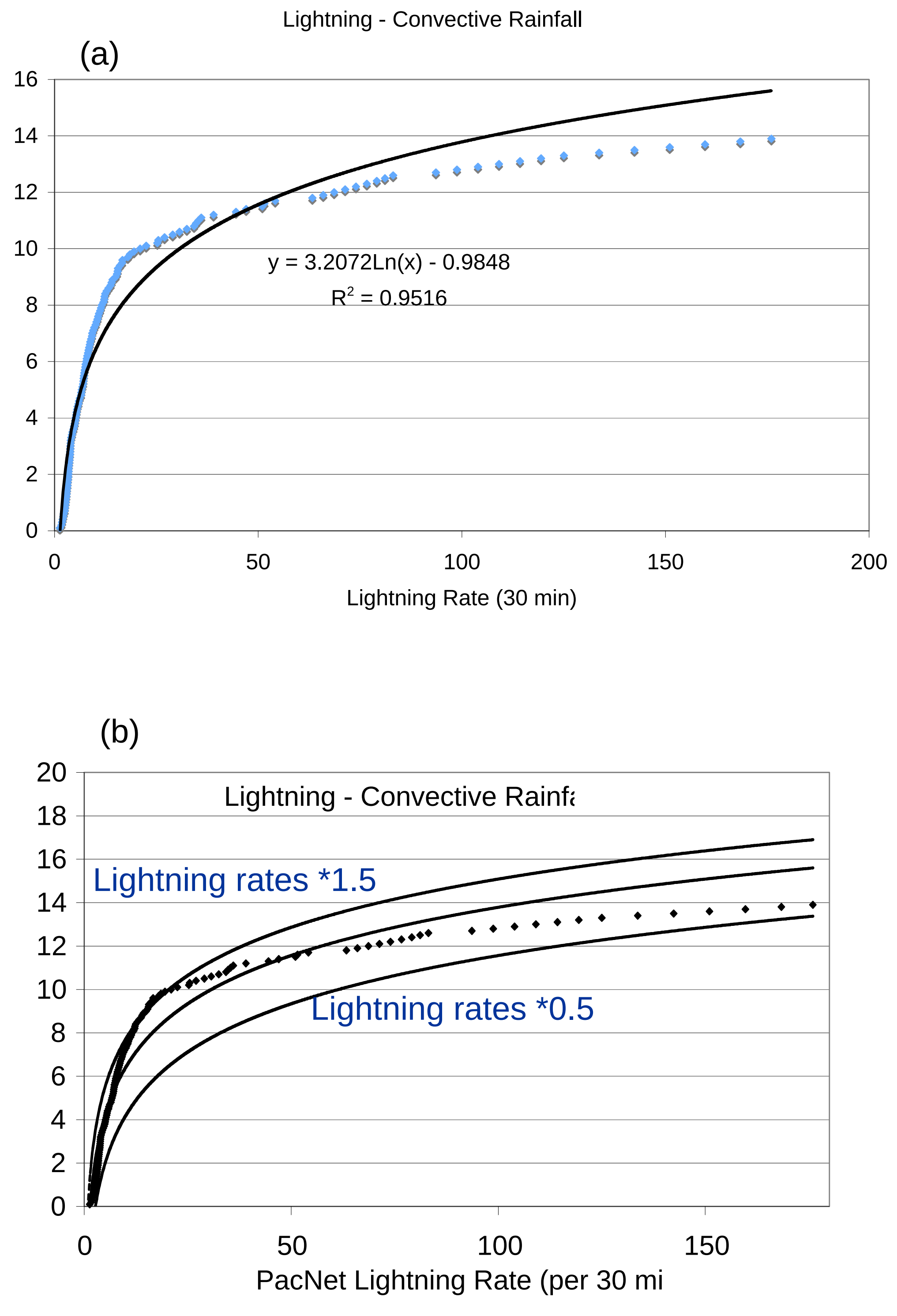

Fig. 3 (a) Relationship of PacNet lightning rate and convective rainfall rate derived from TRMM TMI data based on the cumulative probability matching method. (b) as in (a) with lines for lightning rate multiplied by factors of 1.5 and 0.5, respectively.

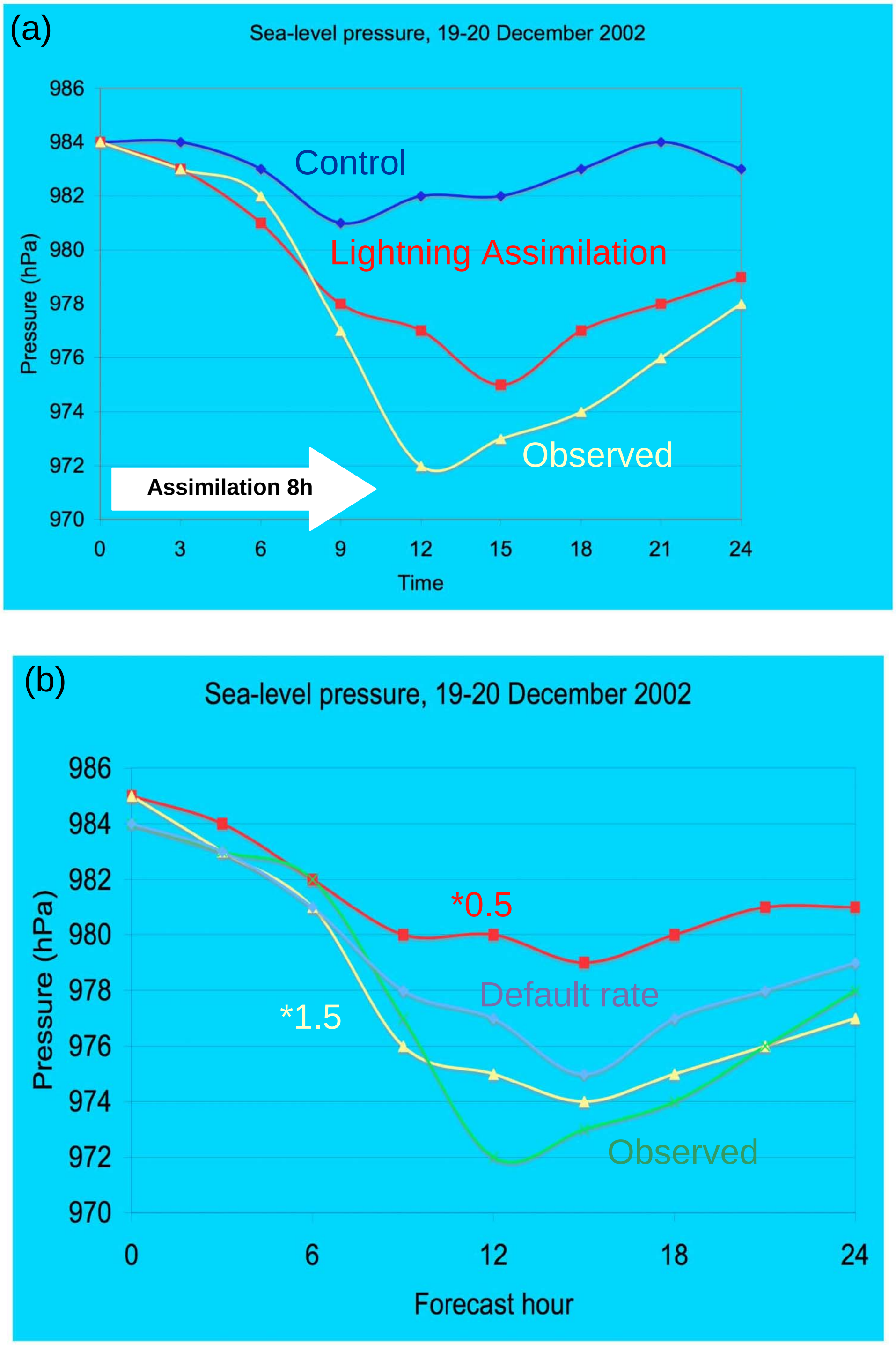

Fig. 4 (a) Comparison of observed storm central pressure (yellow) with that predicted by MM5 on 19 December 2002 with (red) and without (blue) lightning data. (b) Comparison of observed storm central pressure (green) with that predicted by MM5 on 19 December 2002 with lightning rates multiplied by factors of +1.5 (yellow), 1 (purple), and 0.5 (red).

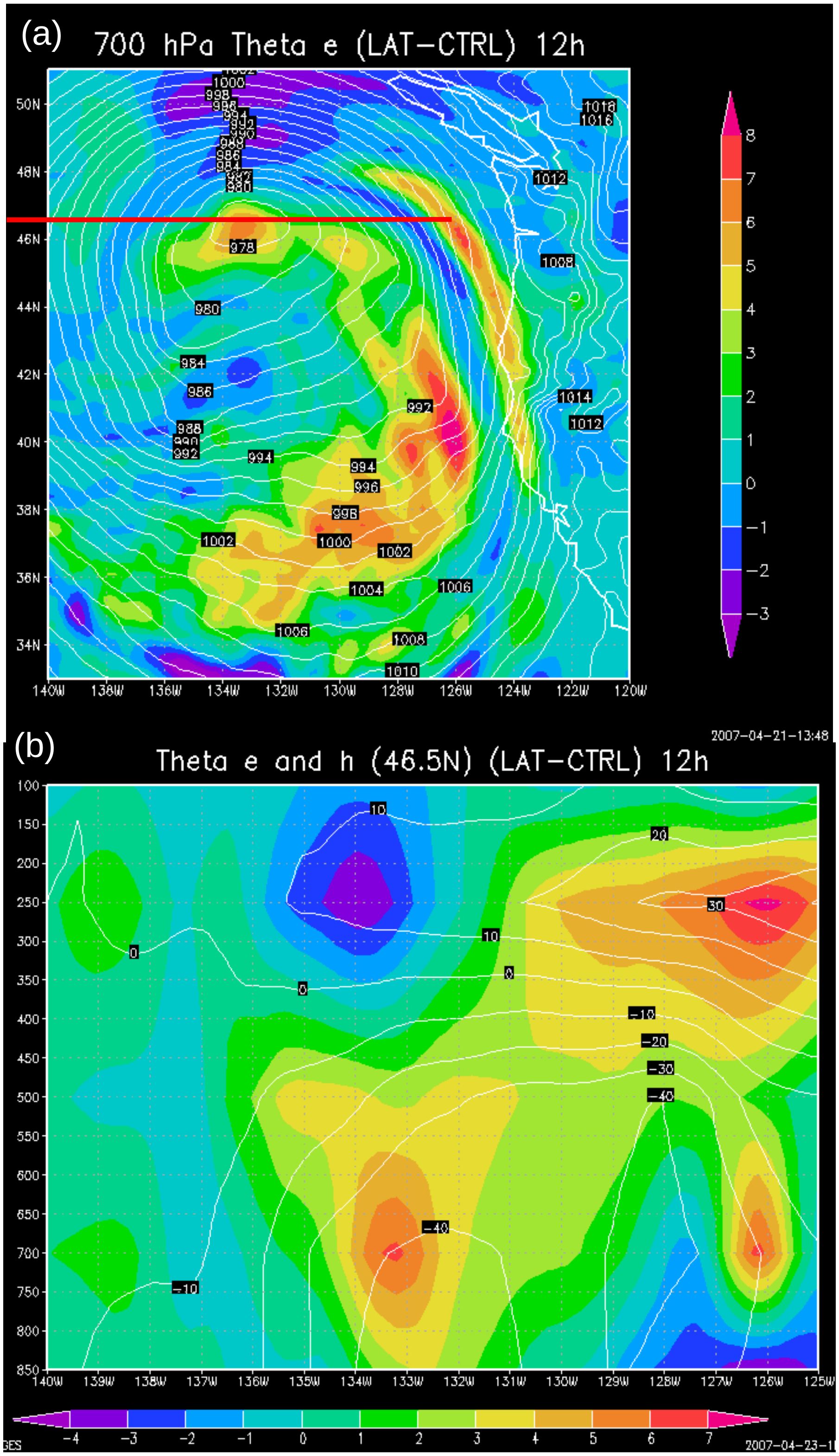

Fig. 5 (a) Sea-level pressure (every 2 mb) and the difference in θ_e between lightning assimilation and control runs (shaded, K). (b) Cross section along 46.5°N (red line) showing geopotential height difference (contours every 10 m) and difference in θ_e between lightning assimilation and control runs (shaded, K).

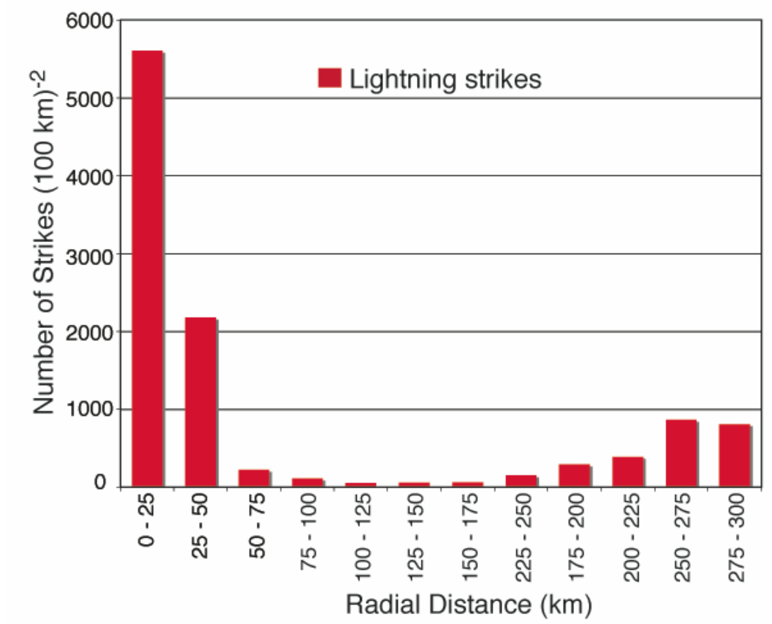

Fig. 6 Radial distribution of lightning strikes in Hurricane Rita between 1800 UTC on 20 September and 0900 UTC on 23 September. Flash totals normalized by the total number of flashes (100 km)$^{-2}$.

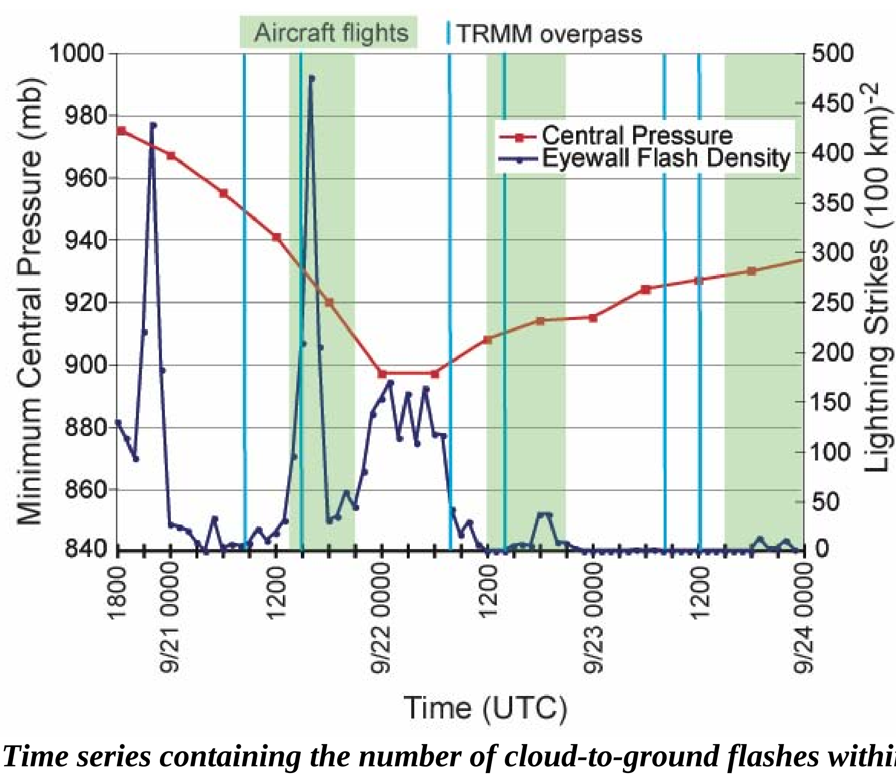

Fig. 7 Time series containing the number of cloud-to-ground flashes within 50 km of the center of Hurricane Rita (blue line), and hourly track of minimum central pressure (red line). Pressure values are linear interpolations of best-track 6 h data obtained from National Hurricane Center. Times when TRMM data (blue line) and aircraft data (green shading) were available are also indicated.

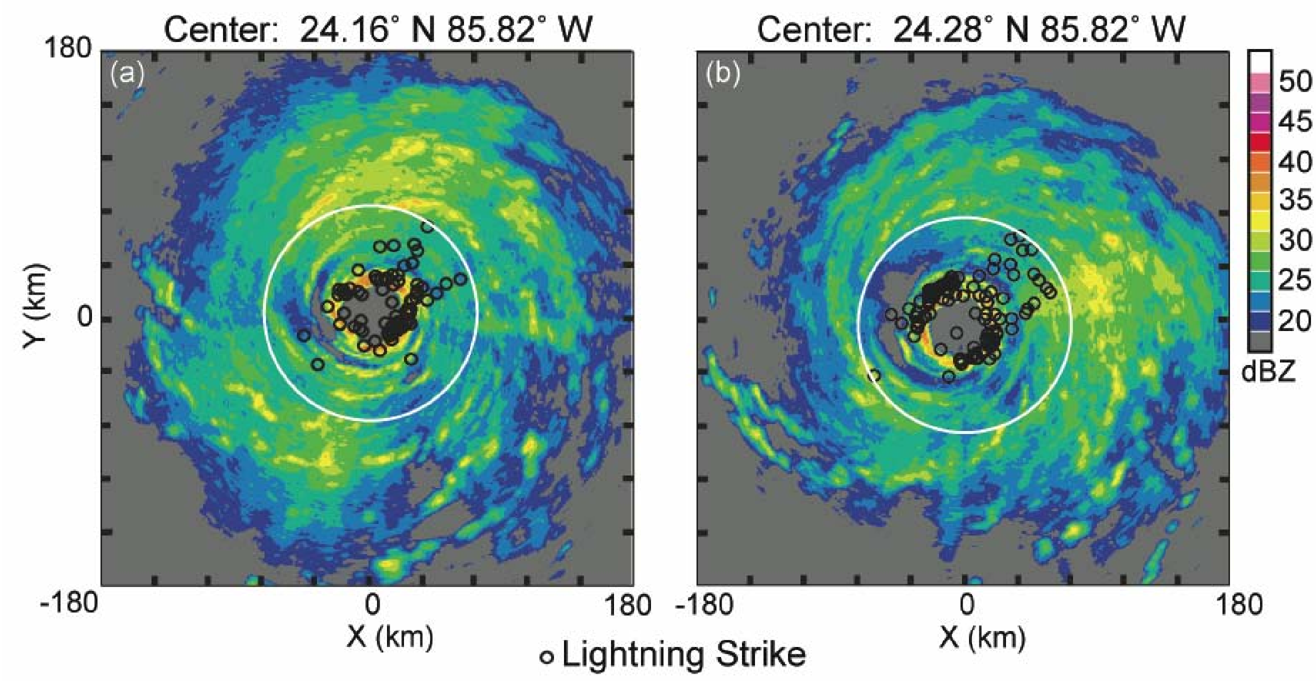

Fig. 8 NOAA P-3 lower fuselage radar reflectivity taken on 21 September while aircraft was located within the center of Hurricane Rita, at an altitude of 2,700 m. The nominal effective range of the LF radar is shown using the 70 km range ring (white circle). Superimposed onto each image is 20 minutes of lightning data (black circles) centered on the time of the image. a) Reflectivity at 1523 UTC, with flash locations from 1513 UTC to 1533 UTC. b) Reflectivity at 1602 UTC, with flash locations from 1552 UTC to 1612 UTC.

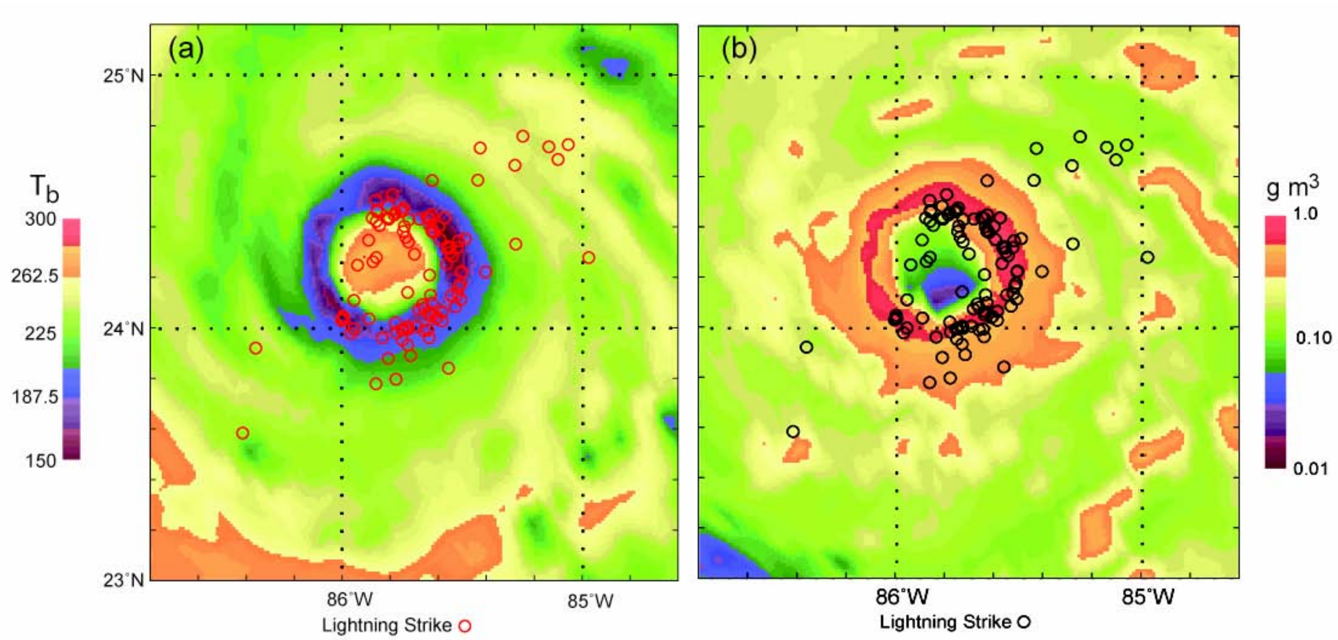

Fig. 9 TRMM data collected at 1540 UTC, with lightning strike locations from 1530 to 1550 UTC on 21 September. a) 85-GHz TMI image with lightning (red circles). b) Level 12 (8 -10 km) PIC image with lightning (black circles).

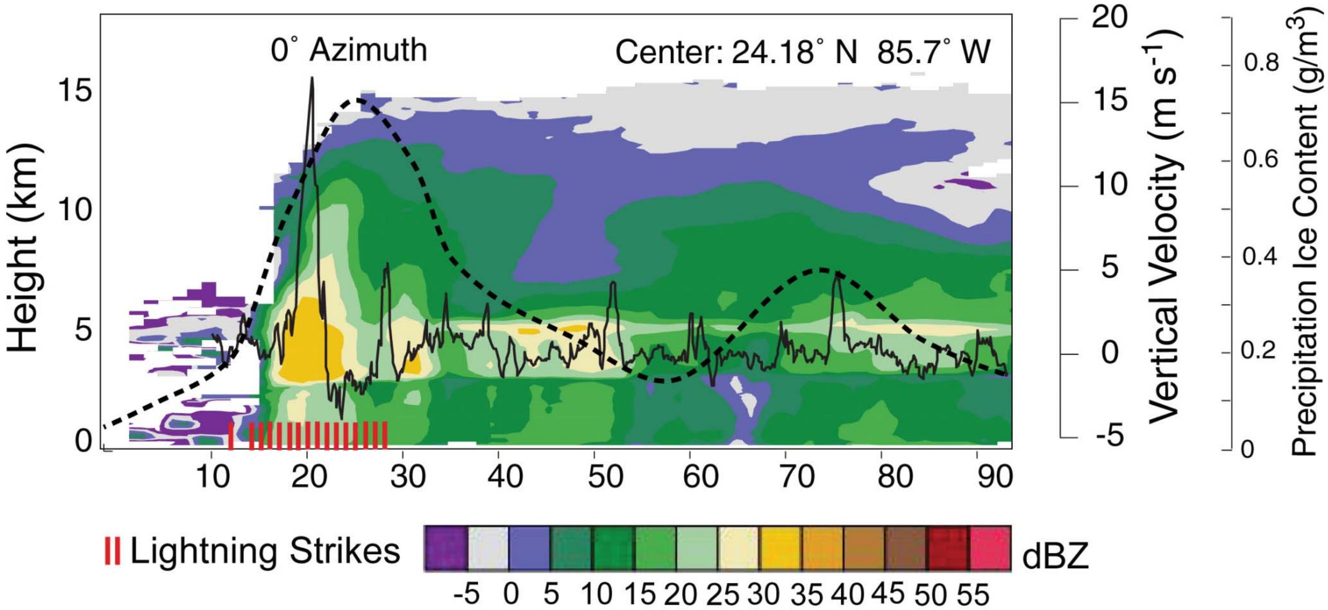

Fig. 10 Vertical reflectivity profile (VRP) composites created by the NOAA P-3 aircraft tail radar during an azimuthal eyewall cross-section flown at 1536 UTC 21 September, with aircraft altitude of 2,600 m and heading of 000˚. Overlaid onto the cross-section is flight level vertical velocity measured along the corresponding flight path (heavy solid line), radial lightning strike locations (red bars) during the time of the radial flight, and radial distribution of level 12 (8 – 10 km) TRMM PIC values (dashed line) obtained from the 1540 UTC satellite pass.